

FIBER OPTICS
A RESEARCH PAPER

by

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ABSTRACT

The purpose of this report is to inform the reader of some basic aspects concerning fiber optics. This paper touches on some history leading up to the development of optical fibers which are now used in the transmission of data in many areas of the world. Basic theory of the operation of fiber optics is discussed along with methods for improving performance of the optical fiber through much research and design. Splices and connectors are compared and short haul and long haul fiber optic networks are discussed. Fiber optics plays many roles in the commercial world. This paper emphasizes the use of fiber optics for communication applications.

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INTRODUCTION

History and General Information

Telecommunications has always researched for new technologies which could expand transmission capacity. When the first laser became a reality in 1960 an interest in optical communications arose. The laser was seen as an optical carrier on which information could travel at an unparalleled rate. Research began on the broad front. It took ten years before a realistic, low-loss, transmission medium was presented. This was a doped high-silica optical fiber which had a loss of 20 dB/km. Continuous-wave operation was achieved at room temperature in the aluminum-gallium-arsenide semiconductor laser. Ten years of research made optical-fiber communications a practical reality. Those in communications are so interested in the use of fiber optics because of the high capacity of information a light beam can carry.

It was ten years ago, in 1977, that fiber optics were incorporated in the telephone network in the U.S. as a trial system. In 1987, a totally new industry has arisen in light wave technology and most industrial nations are hoping to benefit from its resources as manufacturers and beneficiaries. Advances in the lightwave technology are remarkable. Optical fiber can be made so pure that light signals carrying large amounts of information can travel more

than 100 miles without being amplified. The fibers have such little variation across their diameters that light does not reflect or refract from these fibers even over these long distances. The pulses of light do not become distorted after such long distances either. Semiconductor structures generate and detect these light pulses which are transmitted by the fibers.

Lightwave communication is vastly effecting the telecommunications business. Examples of its uses are in the loop area going to the customer premises, the exchange area between central offices in a metropolitan region, long haul intercity arena and the submarine cable area. Optical fiber is already used more than any other type in these areas. Other uses are in data links for small haul networks.

The customer will benefit from lightwave technology because it is cost-effective and provides a bandwidth less expensive than other technologies requiring bandwidth. Price is not the only factor. Lightwave communication now allows cost-effective digital voice transmission on an end-to-end basis. Before now, digital voice transmission could not compete with analog on long haul systems. Communication in the forms of voice, data and image could not be brought together on one universal stream. Due to digital connectivity, many new digital services are arising in the marketplace. Digital connectivity will allow customers virtually unlimited bandwidth at a low price and can be used in a variety of ways. The customer will have the flexible

capability of monitoring and reconfiguring dedicated parts of the network themselves. Lightwave technology has reached maturity. Society may be nearing an era of Universal Information Services. All practical purposes which utilize light sources have spectral purity that doesn't compare to the spectral purity of radio carrier waves. But those sources are not tunable like radio oscillators may be tuned. Technology promises higher receiver sensitivity and an efficient means for channel selection in densely packed wavelength-multiplexed systems.

Basic Theory

The basic unit in any fiber optics system is the fiber itself. The quality of the fiber determines the performance of the whole fiber optic system. This guidance of light is possible because of the multiple reflections which occur along the glass or plastic channels of the optical fiber. If a beam of electromagnetic energy enters the system through one end face of the cylinder then much of the energy, typically the light energy, will be trapped in the system and guided to the opposite end-face of the fiber. The light beam will undergo many reflections causing a total internal reflection to occur in the fiber. Therefore, none of the light attained from the energy escapes causing the message to be received at the opposite end-face of the fiber.

A ray of light inside a fiber has total internal reflection when at the boundary between two dielectric media (an optical fiber). Snell's Law aids in the calculation of the critical angle for internal reflection which exists inside an optical fiber. Snell's Law states:

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

where:

n_1 = the index of refraction for medium one

n_2 = the index of refraction for medium two

θ_1 = the angle of the ray away from medium one with respect to the normal

θ_2 = the angle of the ray away from medium two with respect to the normal

The critical angle for reflection is derived from Snell's Law by setting equal to unity to achieve:

$$\sin \theta_c = n_2 / n_1$$

(See Appendix A on pictures of reflections in fiber optics).

Bettering the Specifications for Optical Fiber

When fiber optical systems were introduced in the late 1970's as a commercial market, the wavelengths of the system were approximately 0.82 micrometers. The multimode fibers that were used had a transmission loss of three to four

decibels per kilometer. Through much research a wavelength range of between 1.3 and 1.5 micrometers was achieved with a transmission loss of 0.5 dB/km in the optical multimode fiber. These systems operated at a rate of up to 200 Mb/s.

At wavelengths nearing 1.3 micrometers the pulse spreading due to the material and waveguide effects (chromatic dispersion) is at a minimum in the fiber. This allows transmission to be achieved over long distances and at very fast rates. In some applications light emitting diodes (LED) are preferred over lasers because of their great reliability, lower cost and less sensitivity to variation in temperature. For example, data links might use LED's over lasers. Using the 1.3 micrometer transmission window allows the use of LED's instead of lasers.

Advancements were then made to improve the 1.3 - 1.5 micrometers wavelength and 0.5 dB/km transmission loss in multimode fibers at a megabit per second rate of 200. The systems now operate at a rate of several hundred megabits per second and can be upgraded to beyond one gigabit per second. The repeater spans of these systems can exceed 40 km. These operate at 1.3 micrometer wavelengths, are laser-based and use single mode systems. Such systems are used commercially today for long haul operations including intercity and intercontinental services.

Laboratory research in lightwave systems is seeking the potential of low-loss, single-mode fibers. At wavelengths of 1.57 micrometers a minimum loss of 0.16 dB/km has been

attained. This is close to the theoretical limit of Rayleigh Scattering. Rayleigh Scattering describes elastically scattering of light that results from various nonpropagating fluctuations in the material's index of refraction. On the contrary, Brillouin Scattering describes inelastically scattering of light that results from the interaction of light and the thermal motion of ions (sound waves). Very little Rayleigh Scattering was expected to occur in single crystal materials. However, because of the residual strain and grain boundaries related to the hot-press-forge such single crystal materials produced larger amounts of scattering.

Design and Performance

Optical static wire has become an increasingly popular item in providing optical communication links along utility right-of-ways. This wire is used in place of ground wires on the overhead power transmission lines. There are many decisions that must be considered when designing such a cable. The most important design features include: optical attenuation, environmental stability, mechanical protection, cable handling and fiber splicing.

The wire is subjected to a wide temperature range as well as atmospheric conditions. The core must be able to withstand elements and the materials used must withstand temperatures between -40 to 70 degrees celcius as well as

temperatures at 250 degrees celcius for brief periods due to lightening. The cable uses buffer tubes made of fluoropolymer with a flexible silicone gel for withstanding the extreme temperatures.

Such a cable must be able to protect the optical fibers. There is a design for the optical static wire which uses a channelled rod which houses the fibers. This pipe must have significant crush strength. The stress on the fiber must be kept at acceptable levels to allow the longevity in a cable to be a reality. Optical fibers may be loose buffered or tight buffered. Loose buffered fibers will be discussed briefly here. Loose buffered designs place the small fiber in a much larger buffer tube. These fibers are coated to make its diameter 250 microns. Loose buffered designs have the potential for an elongation window because of the spacing between the tube wall and the fiber. An elongation window is the allowable cable strength before there is an increase in fiber strain. The elongation window allows for elongation caused by tensile loading and contraction at low temperatures. As the tube is stranded in a helix the fiber can move radially as the cable contracts or becomes longer. This method prevents axial strain on the fiber. The major portion of the strength of the cable comes from standard aluminum clad steel wires which are stranded around the channelled rod.

Optical Static Wire

cable diameter: 0.507 in.

cable weight: 0.352 lbf/ft

rated break strength (RBS): 17200 lbf

fault current capacity: 65 kA(squared) - seconds

fiber capacity: 2 - 12

(See Appendix B for more description on various fiber optic cables and other fiber optic equipment).

Loss and dispersion are the main influences that control the performance of high-bit-rate lightwave systems. Low dispersion means higher bandwidth. There exists a lower transmission loss in the single-mode fibers as opposed to the multimode fibers. This is because single-mode fibers have a lower intrinsic loss due to Rayleigh Scattering because their dopant concentration is lower in the core. Dispersion in single-mode fibers occurs because spectral components radiating from an optical source travel with different group velocities in a fiber and therefore arrive at different times at the output. Dispersion effects broaden the width of pulses as they propagate along a fiber. The performance degrades if the distorted output overlaps adjacent time slots.

But single-mode fibers are not really "single-mode". They are actually bimodal due to the presence of birefringence.

Birefringence is the refraction of light in two slightly different directions to form two rays. It is normal for a single mode optic fiber to propagate two fundamental modes with orthogonal polarizations. Between two directions (x and y) there is difference in the propagation constants, $(\beta_x - \beta_y)$,

which defines a modal birefringence, $B = (B_x - B_y) / (2\pi/\lambda) = \lambda/L$ and a beat length L for wavelength λ .

Highly birefringent fibers can maintain a given mode of linear polarizations over lengthened distances. Moderate birefringence allows orthogonal modes to be coupled by frequent disorders caused by environmental built-in factors. Low birefringence can maintain polarization and/or allow Faraday rotation by magnetic fields to be observed if no outside disorders are allowed.

Manufacturing Techniques

Due to the large scale production of optical fiber since 1979, the cost has decreased significantly. Much of this decrease in cost is caused by the experience learned in production of the fiber. There is both the demand to increase the production rate of the fiber and improve its performance. Most of the glass used to make the fiber is cladding.

Cladding is something that acts as a cover or coating. It is desirable to achieve a coating for optical fibers that prevents water from corroding the fiber and to aid in strengthening it. Fiber optic glass rods doped with Al_2O_3 and ZnO in sodium-borosilicates help to improve the water resistance of the rods. To improve static fatigue characteristics of optical fibers, a thin surface-compressive

of three- or four-layer structured fibers can be applied. There is hope that techniques will arise to produce this cladding glass as quickly as possible.

The modified chemical vapor desposition (MCVD) process was invented in the early 1970's by AT&T Bell Laboratories. A high-purity dry vapor of SiCl_4 , vapors of GeCl_4 and fluorinated hydrocarbons are passed through a rotating silica substrate tube with pure oxygen. The tube is heated by an oxyhydrogen torch. The contents react and silica glass particles are formed which are doped with the germanium and flourine. Away from the reaction these particles are driven to the tube walls where they deposit. The previous moving torch then passes over this deposit and sinters it into a thin layer of doped glass. Many layers are deposited with the passing of the torch. Then, the quartz tube is heated to high temperatures by moving the torch along the length of the tube. The glass will approach a softening point and surface tension caused the tube with the deposited glass layers to collapse uniformly into a solid rod called a preform. The preform is put into a high-temperature furnace and a fiber is drawn. The standard outside diameter is 125 micrometers. A 60-micrometer-thick polymer is added to the outside of the fiber to protect the glass surface from damage. This type of coating enhances subsequent cabling and splicing operations.

The majority of optical fiber produced is single-mode. Multimode fibers are still important for local area networks. Single mode technology is the lightwave technology of choice

for high-capacity, long-haul, metropolitan interoffice and subscriber loop feeder systems. This depressed-cladding single-mode fiber provides low intrinsic loss high bandwidth, low splice loss and a high resistance to macrobending and microbending-induced losses.

Splices and Connectors

In long haul systems low loss cable and fiber splicing are used to minimize path loss. However, in loop distribution networks, easy cable handling and rapid splicing are essential.

The purpose of splices and connectors is to interconnect the transmission media and to connect the media to optical devices. Splices for the most part are designed to be a permanent connection. Connectors are designed to be frequently disconnected and rejoined. When rejoined, splices have to be replaced of matching gels or adhesives and maybe repolished. Connectors need to be only cleaned before rejoined. The most significant system parameter concerning splices and connectors is optical loss. Optical loss is directly proportional to how well the fibers are aligned when connected. The cost of the connection is usually dependent on how accurately the fibers are aligned.

There are two basic approaches to the splicing of optical fibers. These two methods are fusion welding and

mechanical joining. Both methods involve three basic steps: 1) Fiber end preparation, 2) Alignment of the fibers and 3) Retention of the fibers in the aligned position.

Arc fusion is one method for splicing optical fibers. In this process, the fiber ends are severed and aligned and then melted and fused to retain the alignment. For a single-mode fusion process, the fibers are aligned with x-y micropositioners. These micropositioners are driven by a feedback signal which peaks the transmission of the splice. The quality of the splice is still vulnerable to variation when the execution of those three basic steps is carried out. Environmental conditions can prove unfavorable as well in the accuracy of the splice.

Mechanical splicing is another method for splicing optical fibers. In this method, the ground and polished ends are aligned and then butted together with a matching gel or a type of adhesive between the ends. The alignment of the fibers is done mechanically. Using the proper gels and adhesives, reflections caused from the fiber end faces can be made negligibly small.

It is essential that a quick and inexpensive method be devised to connect optical fibers when building systems in volume. This has slowed the use of fiber optics in aerospace and industry. In January 1987, ITT/Cannon announced that it had a faster way to link optical fiber. Calling it's technology "fiber-lens fusing" ITT/Cannon says it can cut the high costs related to fiber-optic connection with new speed

and simplicity. This new method is different from the existing methods of grind-and-polish or crimp-and-cleave. It uses a fusing unit which melts the end of the fiber with a high voltage arc and forms a lens. An optical connection is made when two ceramic contacts link the lenses. This method is supposed to be as easy as splicing copper wire.

Fiber optic connectors are becoming more reliable, better designed and standardized. They are becoming increasingly popular in telecommunications, data communications and military and aerospace applications. The main purpose of a connector is to act as a nonpermanent connection between two optical fibers to an active device, like an emitter or detector, or to a passive device, like a branching device or attenuator. Splices are inseparable junctions of optical fibers for the most part. Connectors must prove to have a low insertion loss and must show good repeatability of this loss over many cycles. Temperature, vibration or cable tension must not be major contributing factors to connector loss. Three major types of fiberoptic connector designs include: "bare-fiber" connectors, ferrule connectors, and expanded-beam connectors.

"Bare-fiber" connectors are temporary mechanical splices. The fiber is aligned to another by an internal detail of the bushing. These "bare-fiber" connectors are not commercially viable because they do not protect the fiber ends.

Ferrule connectors do protect the fiber by encasing it

in a cylinder or cone much larger than its diameter. The joining of the fibers is done by aligning the two larger objects. The Ferrules are aligned instead of the fibers.

Expanded-beam connectors collimate the rays of connecting fibers thus creating core diameters to become much larger than the diameter of the fiber itself. They reduce the affects of radial misalignment and endface contamination. However, they are more susceptible to angular misalignment.

Short Haul Networks (Data Links)

Fiber-optic data links are being used for applications in which distances are short and cost, size and reliability are paramount. Examples of such users might include local area networks (LAN's), a campus computing facility where there is a moderate amount of information being exchanged from several locations, factory automation, office communications. Fiber-optic data links for such uses are cost effective and work much better than copper interconnections. These small hauls are different to the long haul transmissions needed for telephone networks, for example, which involves very high capacities and long distances. These data links typically use low-cost light-emitting diodes (LED), multimode fiber and simple junction photodetectors.

LONG HAUL NETWORKS

Development of Fiber Optic Broadband Interactive Distributive Network (FOBID)

Fiber optic subscriber loops are being explored worldwide. There are two basic approaches. One involves using a broadband ISDN based on completely digitized subscriber loop systems using single mode-fibers and LD's and LED's. This approach seems to be a reasonable approach for subscriber loops except the cost is too great to become a reality in the present. The other approach is to seek more realistic measures for subscriber loops in the broadband range. Such measures might include use of multimode optical fiber (due to economy). However, economy cannot be the only factor. The services for the customer must be made attractive. The use of broadband optical cables offers such characteristics. The center-to-end broadband distribution service appears most satisfactory. The designers of the FOBID network believe it can offer such a service.

The FOBID network involves the use of node equipment, trunk lines and subscriber loops. (See Appendix C for a picture of the FOBID network). A subscriber loop transmission system consists of a fiber-optic office unit (FOU), fiber-optic service unit (FSU) and optical cable. A broadband channel selector (SEL) is set up within fiber optic subscriber equipment (FSE) at the node office. According to

the subscriber's request the SEL will select an arbitrary broadband channel (W). This is done through a signaling path (D) from many broadband sources provided by many operator centers. Broadband sources can hold 60 channels and eight operators can be connected to this network. A two-way data channel can be used when necessary between the operator center and each subscriber.

FXNET: A Backbone Ring of Voice and Data

The span for most local area networks (LAN's) is not large; typically around a kilometer. Therefore a single LAN cannot satisfy the needs of larger organizations. The reason for this is the distance that the facility covers is too large and there are more stations to be attached to the system than can be handled by a single LAN. A whole facility can be covered using a pure voice PBX, however it seems more beneficiary to distribute the function of the PBX into smaller packages and bring these packages closer to the user. Integrating LAN/PBX's provides high data bandwidth that LAN's offer but limitations on wiring distances exit. The communication needs of an organization usually involve both voice and data. To serve these needs local LAN's and PBX's serving individual groups, can be interconnected by a form of high bandwidth backbone network. FXNET developed by BNR can provide such a network to interconnect an organizations LAN/PBX's, PBX's, and LAN's within a building complex,

campus, or metropolitan area. It also provides high bandwidth interconnection to mainframe computers, to shared resources and to workstations, like CAD work stations, that require more bandwidth than is provided on normal LAN's. This is cost effective to have a single backbone facility which can handle both voice and data instead of separate facilities for each service.

FXNET is an active fiber optic ring that operates at a frequency of 160 MHz and gives a data rate of 80MB/sec. An active ring with a single link connecting each station means that all stations and links must be operational or the whole ring is brought down. A bypass operation has been studied where each station has primary and bypass links. The bypass links are used to skip a station and go on to the next. Another idea is to use dual links. The second link would carry a signal in the opposite direction to the first link.

Presently, it is not intended for FXNET to be supplied to every person. PBX's Integrated LAN/PBX's and normal (lower speed) LAN's will perform the end-user distribution of voice and data (as well as switching locally). FXNET is used as a backbone ring and FXNET stations are normally bridges. The combined system is referred to as a campus network or metropolitan area network (MAN). This includes the backbone ring plus end-user (DTE).

A fantastic motivation for interconnection is to share resources. When small groups are involved on small LAN's, very informal methods of locating and sharing resources is

sufficient. However, more sophisticated methods are needed when the number of resources and the number of people needing to use those resources becomes very large.

The communication needs of many organizations closely match the FXNET network briefly discribed. Thanks to fiber optics such a network is possible.

Fiber Distributed Data Interface (FDDI)

The emerging Fiber Distributed Data Interface (FDDI) standard is predicted to have a major impact for interconnecting computers and peripherals. FDDI is aimed at the connection of computers and peripherals using fiber optic media. This network can be subdivided into several categories. Some major categories include local area network (LAN), campus area network (CAN) and wide area network (WAN). This network uses a ring topology, token-passing access and base band modulation.

Proteon is one of the many companies supporting fiber optic networks. This company's network is Pronet-80 which has 80 Mb/s, token passing and is used to link mainframes, mini computers, microcomputers, workstations and intelligent controllers. This company plans an upgrade in their network using FDDI which uses a 62.5 micron-fiberoptic cable.

There are three types of fiber optic media: stepped index, graded index and single-mode. The difference in these three determine the amount of loss in the cable. The single-

mode fibers allow lengths of up to 40 km without splicing and they are more suited to LED sources. Stepped index and graded index are more suited for use with laser light.

The purpose of the FDDI specification is to let the media carry data. However, FDDI isn't the only fiber optic solution. Many companies utilize fiber optic replacements for twisted pair and coax. Artel Communications utilizes a network called Fiberway. Fiberway is a 100-Mbit/s fiberoptic digital LAN with multiple channels. It uses time-division multiplexing to manage two 50-Mbit/sec channels or four 50-Mbit/sec channels off of one cable.

Summary

When dealing with fiber optics it is important to keep in mind many different areas. Understanding the theory behind the operation of optical fiber is very important if improvements are to be realized. The system can be made more efficient by improving the specifications, design, and manufacturing of the optical fiber. Today fiber optics is utilized in many different types of communication networks as well as other areas of the commercial world. Optical fiber is being improved causing it's future to look promising. It seems that industrial uses for fiber will be very widespread.

Conclusions

The field of Fiber Optics has come along way. Research began close to ten years ago into the development of optical fibers for the transmission of information. After many years of research materials were developed, as were methods revised to keep bettering the fiber optic specifications. Presently, fiber optics is not only a reality, but a practical reality. Fiber optics is used in many aspects of the commercial world. In particular it is used for communications. Vast amounts of information can be sent in a pulse of light, through optical fibers, and it is used by almost everyone every single day. Future uses for optical fiber seem very promising. Many areas of industry are discovering that fiber optics could be helpful in improving their operations.

APPENDIX A

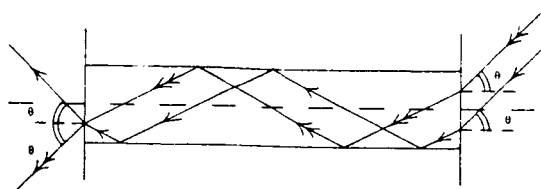


Fig. 3 The passage of two parallel light rays through an optical fibre, where the number of reflections differs by one.

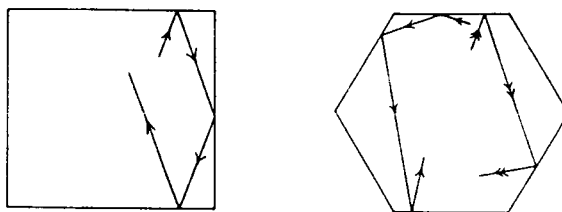


Fig. 22 Projection of the paths of skew rays in optical fibres of square and hexagonal cross-sections on to a plane normal to the fibre axis.

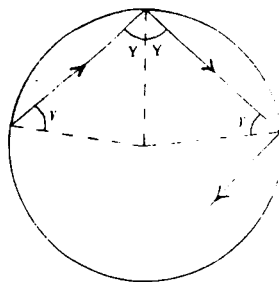


Fig. 18 Projection of the path of a typical skew ray on a plane normal to the fibre axis.

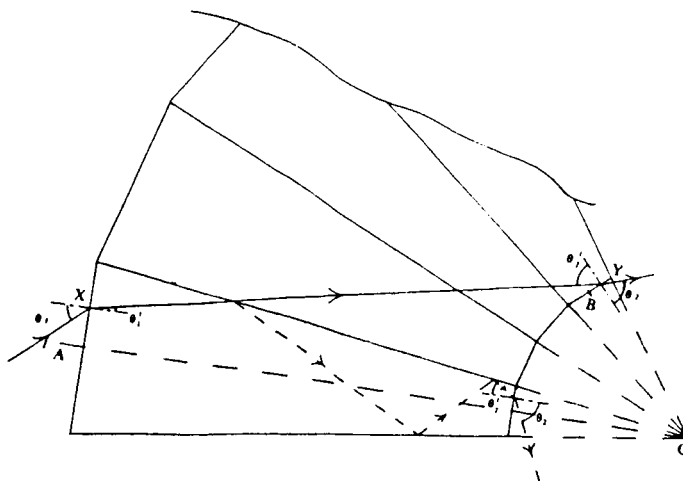
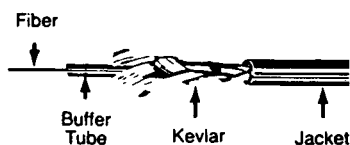


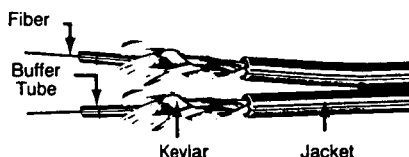
Fig. 15 Representation of the passage of a typical meridional ray through a conical optical fibre.

APPENDIX B

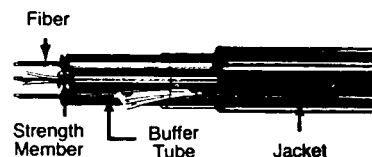
Single Fiber



Duplex



Multifiber

**Common Purpose Loose Buffer Cables**

Our common purpose cables utilize a loose buffer tube construction and are suitable for indoor installation in duct, tray or conduit. The individual fibers are enclosed in plastic buffer tubes. This minimizes the cable's attenuation losses caused by microbending or expansion and contraction.

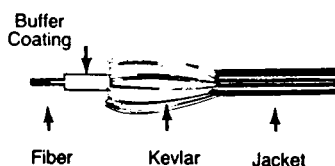
In the single fiber and duplex cables, the buffer tubes are covered with a Kevlar® braid either 8 or 16 ends, which provides the load bearing support for the cable. An outer jacket of PVC is extruded over the braided buffer tubes to provide a durable, yet flexible cable for duct, tray or conduit installation.

The multifiber cable configuration consists of 4, 6, 8, 10, 12, or 18 optical fibers enclosed in individual color-coded buffer tubes stranded around a dielectric strength member. The

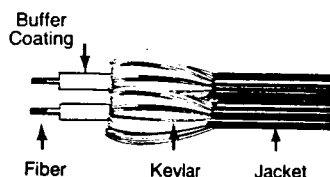
strength member consists of multiple strands of Kevlar®. A mylar polyester tape is wrapped around the tubed cable core assembly to maintain the alignment of the tubes and a rip-cord is added to the stranded cable core to permit easy access to the individual fiber tubes for connecting and splicing. An outer jacket of flame retardant PVC is applied to provide environmental and installation protection or duct, tray and conduit applications.

General purpose cables are all dielectric and pass the U.L. VW-1 flame test. They exhibit stable optical performance characteristics over the entire range of -10 to 50C (+14F to 122F).

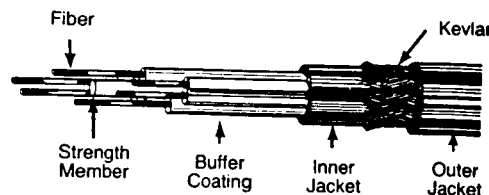
Single Fiber



Duplex



Multifiber

**Tight Buffered Cables**

A rugged tight buffered construction offers outstanding cost-effective trade-offs with conventional wire and coax for computer, instrumentation and control applications.

These constructions were designed for indoor installation in tray or conduit. This construction is ideally suited for shorter transmission distances where flexibility, crush resistance and light weight are key selection criteria.

These products have been designed to conform to the mechanical and optical specifications of DOD-C85045.

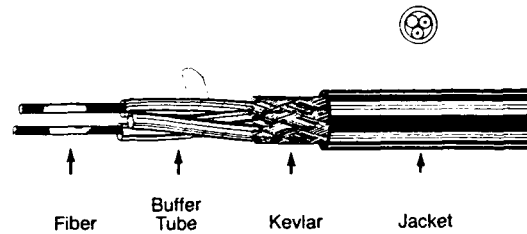
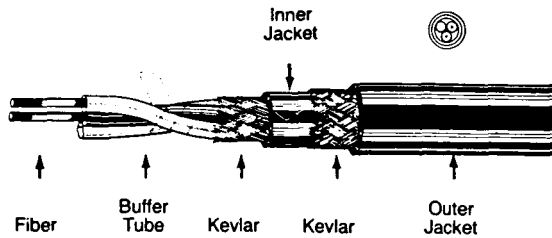
The cables utilize the tight buffer style of construction where an additional jacket of TPE plastic is extruded directly over the optical fiber to provide added crush and impact resistance.

In the single and duplex cables, the TPE buffered fiber is concentrically surrounded by a serving of Kevlar® yarn for

added tensile strength and protection. An outer jacket of flame-retardant polyurethane completes the cable structure. The duplex cable is a figure 8 or zip-cord type construction for easy termination with single channel optic connectors.

The multifiber construction consist of 4, 6 or 8 TPE jacketed fibers stranded around a central stabilization member, an inner jacket of polyurethane encased in a braid of Kevlar® yarns and an outer polyurethane jacket. The stabilization (strength) member is either fiberglass epoxy rod or steel, depending upon the requirement of the installation for additional strength or all dielectric construction.

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Multipurpose Cables

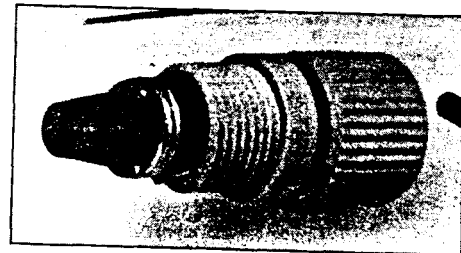
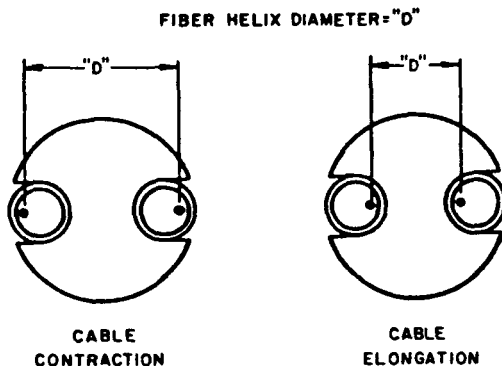
The multipurpose high performance cables designed for combination indoor and outdoor applications, especially where a broad operating temperature range, -40°C to 80°C (-40°F to 176°F), is required. The cables are all dielectric and are available with two different jacket constructions for use in aerial, direct burial, duct or conduit installation.

The basic cable configuration consists of two optical fibers enclosed in individual color-coded, gel-filled buffer tubes stranded with a third empty tube or filler member. A mylar polyester tape is wrapped around the cable core—which is then encased by a braid of Kevlar®. The Kevlar® braid serves as the longitudinal strength member for the cable.

Two different jacket constructions are offered, depending upon installation requirements.

The cable with PVC outer jackets are compounded of black flame-retardant PVC which meet the U.L. VW-1 flame test for duct, tray and conduit installations.

The PE jacketed cables have an inner PVC jacket, a second Kevlar® braid and an outside jacket of black polyethylene. This cable is well suited for combination indoor/outdoor applications where aerial (lashed), direct burial and duct installation will be required.



140 NM BICONIC CONNECTORS

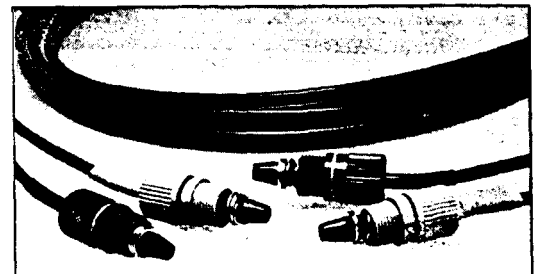
A biconic connector which is compatible to AT&T™ series 1006A connector group. Used on 100/140 micron fiber.

SHE 6339106 (Black)

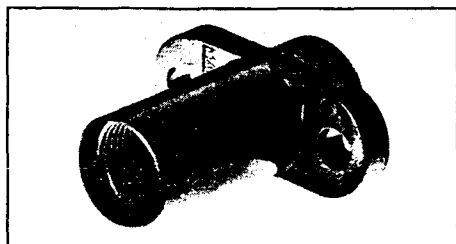
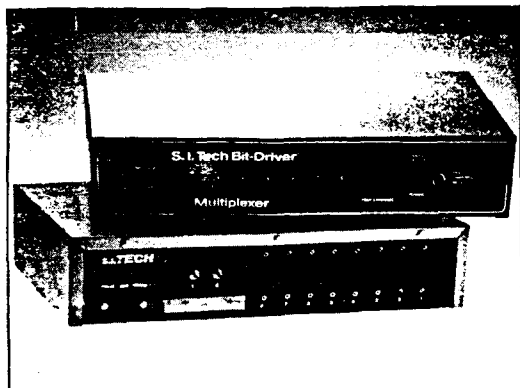
BICONIC TO BICONIC 140

Duplex fiber optic pre-assembled multimode 100/140 Duplex cable using four color coded (transmit-receive) biconic connectors. Used with the IBM token ring or IBM cabling system products, IBM 8219 repeater.

SHE 6165812 Pre-Assembled PVC 100/140 Duplex 8 ft.
SHE 6165813 Pre-Assembled PVC 100/140 Duplex 30 ft.



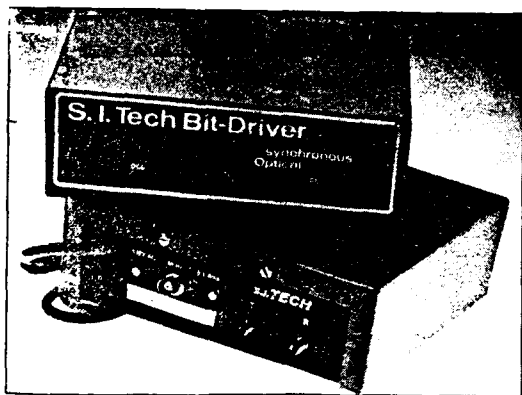
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BICONIC MULTIMODE BULKHEAD ADAPTER

A biconic multimode bulkhead or in line adapter. Used to splice two assembled biconic terminated cables together. Also used when testing an unknown cable assembly.

SHE 5454617



FIBER OPTIC 8 PORT MULTIPLEXER

This Multiplexer is ideal for in-house data transmission where you have clustered terminal situations. It delivers eight full duplex ports capable of moving up to 19.2K bps in either synchronous or asynchronous modes, without using flow control or buffering techniques, resulting in absolute minimum throughput delay. Aggregate speed is 160K bps. Each port on the multiplexer is fully independent, allowing mode (synchronous or asynchronous) mixing. There are five switch-selectable synchronous data rates per channel.

The FMX2006 is an eight channel communications system, that provides links using one optical cable interface. Fiber optic cable offers complete immunity to EMI/RFI interference problems for secure data transmission in noisy environments. Status indicators show the activity of each channel and the integrity of the link. If a problem develops, you can select a digital loopback for any channel at both ends of the link without interrupting the data flow on the other seven channels. If transmission line problems are suspected, an analog loopback can be selected and the cable will be included in the test loop. Maximum operating distance is 6600 feet (2Km). UL and CSA listed. Meets FCC requirements of class A, part 15 computing device standard.

SPECIFICATIONS:

- **OPERATION MODE:** Asynchronous or synchronous, simplex or full duplex.
- **INPUT/OUTPUT INTERFACE:** RS-232-C, to 19.2K bps
- **PHASE DISTORTION:** Less than 12.5%
- **RTS/CTS DELAY TIME:** 0
- **OPTICAL POWER INTO 300 MICRON CORE FIBER:** 400 microwatts
- **TRANSMISSION WAVELENGTH:** 820 nanometers
- **OPTICAL CONNECTOR:** SMA or AMP Optimate connector receptacle

SHE FMX2006 8 Port Fiber Optic Multiplexer

COAX TO FIBER OPTIC MODEM

The FMD2870 is designed to work with 93 ohm coaxial cable, (RG 62/U type) used by IBM in SNA environments. It is ideally suited to replace coaxial cable between IBM 3274, and 3276 controllers and 3278 terminals. It can also be used between IBM 3299 multiplexer and remote multiplexer. The normal operating data rate is 2.35 MBps.

The FMD2870 is a stand alone product allowing easy change from coax to fiber; Simply disconnect the BNC connector and plug the FMD2870 into the input/output port. Meets FCC requirements of class A, part 15 computing device standard.

SPECIFICATIONS:

- **OPERATION MODE:** Synchronous, simplex or full duplex. 2.35 MBps
- **INPUT/OUTPUT INTERFACE:** 93 ohm coaxial cable BNC bulkhead jack
- **TRANSMISSION LINE INTERFACE:** 2 SMA connector fiber optic receptacles (50, 100, or 200 micron core) 2 KM-6600 ft. (5 KM option)
- **TRANSMISSION DISTANCE:** 10 microwatts into 50 micron fiber
- **TRANSMITTER OUTPUT POWER:** 820 nanometers
- **WAVELENGTH:** 820 nanometers
- **RECEIVER WAVELENGTH:** 820 nanometers
- **MINIMUM SENSITIVITY:** 1 microwatt @820 nanometers

SHE FMD2870

Coax Fiber Optic Modem

APPENDIX C

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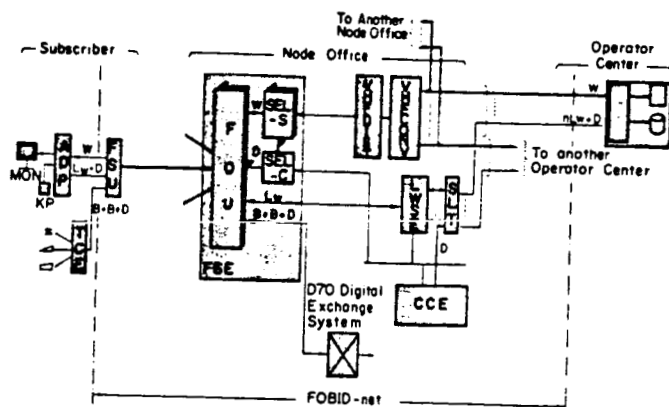


Fig. 1. FOBID-net system configuration.

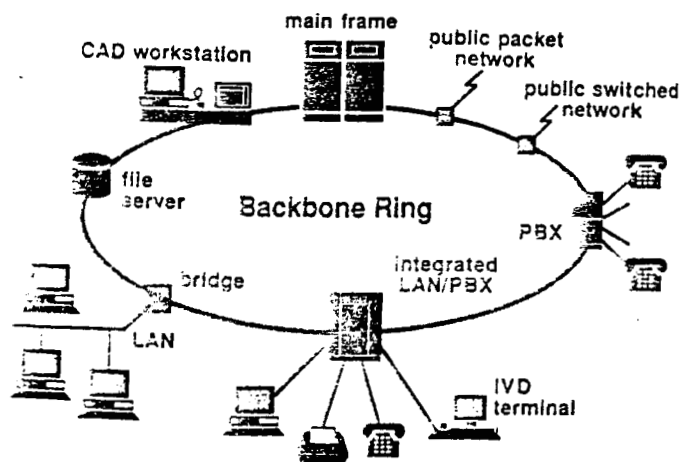


Fig. 1. Backbone Ring Applications.

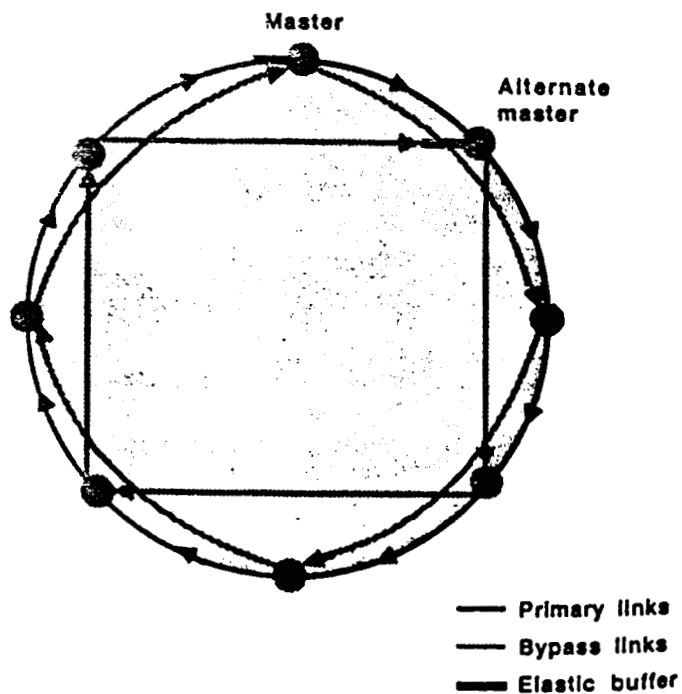


Fig. 2. Bypass Topology.

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